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EXPERIMENTAL INVESTIGATION OF PCM USING RESPONSE SURFACE METHODOLOGY ON SS316L STEEL

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ABSTRACT

Photochemical machining (PCM) is the non-conventional machining processes which produce burr free & stress free flat complex metal components. In the present work optimization of process parameters for Photo chemical machining of SS316L by using response surface methodology. Mathematical models have been developed to study the effect of input parameters on Undercut from the results of the experiments. The different input parameters such as time, concentration and temperature were set during the photochemical machining. Design of Experiment was done by centre composite design method by having 20 experiments to see the effect on etching of SS316L. Minimum Undercut was observed at the etching temperature 63.99, etchant concentration 769.69 gm/lit and 46.96 min etching time. The optimum material undercut was found 0.0815 mm.

Keywords: Photochemical Machining (PCM), Undercut Response surface methodology (RSM), Centre composite design, SS316L.

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1. INTRODUCTION

Photochemical machining basically removes material by chemical action. The features are produced by exposing the work piece of interest through a photographic mask and chemically etching away areas that disappear the features of interest. The method is relatively modern and became recognized as a manufacturing process about fifty years ago [1]. So the stresses and defects that normally arise from metal cutting or any other non conventional machining process are absent in the final part. There are no changes in mechanical properties and chemical composition such as hardness, grain structure, or ductility during the process. Because photo tools don't wear, tolerances stay the same regardless of how many parts are produced with precisely control the dimensions. The increasing application of photochemical machining as an option to stamping for the manufacturing of small, burr free, stress free parts and the trend towards ever smaller and more complex designs of different applications has brought the problem of undercut. Fig. 1, show Undercut is the difference between the final width of the etched feature across the top (B) and the width of the developed resist line (A). The factors affecting undercut are grouped into three broad areas, concentration, time and temperature. To improve the product quality proper selection of PCM process parameter is very important. In this paper we used Response surface methodology (RSM) to optimize the process parameters of PCM on SS316L with consideration of output parameter such as Undercut is reported. Analysis of variance (ANOVA) is done for identifying significant factors.

From literature, it is found that no statistical study has been reported to investigate the interaction effects of input parameters on etching process of SS316L. To improve the product quality proper selection of PCM process parameter is very important. SS316L (nickel-chromium alloy) is a typical engineering material for applications which have need of resistance to corrosion and heat as like in medical devices such as the surgical blade. SS316L has excellent mechanical properties and having desirable combination of high strength and good workability with corrosion resistance. The chemical composition of SS316L is shown in Table I. The high nickel content in SS316L alloy gives the resistance to corrosion by many organic and inorganic compounds. Chromium confers resistance to sulphur compounds & oxidizing conditions at high temperatures or in corrosive solutions. The adaptability of SS316Lhas led to its utilization in a variety of applications involving in chemical industry and medical equipments.

TABLE I. Chemical Composition of SS316L

C	Mn	Si	Cr	Ni	Mo	P	S	N	Fe
0.03	2.0	0.75	16-18	10-14	2-3	0.045	0.03	0.10	Bal

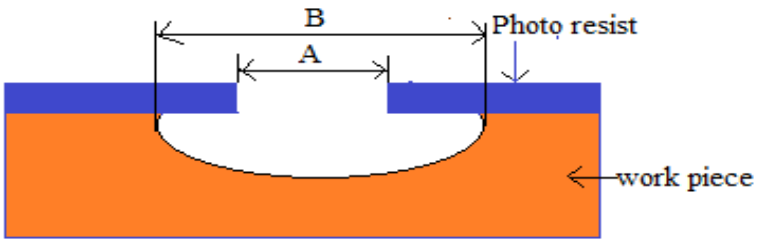


Figure 1 Undercut

2. EXPERIMENTAL DESIGN WITH MULTIVARIATE

Response surface methodology (RSM) is a sequential form of experimentation used to find out or optimize output response variables made up of mathematical-statistical model of many number of input variables [7]. RSM was used in this study to check the effect of different input variables on Undercut during the PCM process of SS316L material, where centre composite design (CCD) requires 20 number of runs to cover all possible combination of the three input variable with three level of each input variable which consist of 8 factorial points with its origin at the centre, 6 star points fixed axially at a distance from the central point to generate the quadratic values & 6 replicates of the centre point. The centre point have vital role since it represents a set of experimental conditions at which six independent replicates were run. The deviation between them reflects the variability of all design. In this model each input variable was investigated at three levels. The model was developed with the responses and their optimization was done using ANOVA to estimate the statistical parameters by using response surface methodology. In this paper optimization process is based on three major steps first performing the statistically designed experiments then evaluating the coefficients in a mathematical model and finally predicting the response. Input parameters and their levels are shown in Table II.

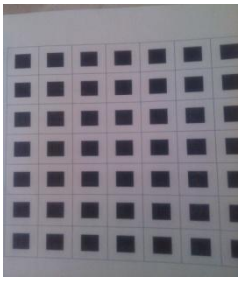
Table II. Input Parameters and Their Levels

Factor/coding	Notation	(-1)	(0)	(+1)
Time (min)	A	30	45	60
Temperature (^{0}C)	B	50	65	80
Concentration (gm/lit)	C	600	750	900

3. EXPERIMENTAL PROCEDURE

In this research work experiments were performed according CCD. In the process first of all make a drawing of square shape having dimensions 10mm*10mm by using AUTOCAD and print this square section on a transparency paper so photo tool is ready to use. Work piece first chemically as well as mechanically cleaned so the photo resist can adhere. Dip the prepared work piece in photo resist for some minutes such that a thin layer is produced on the specimen. After photo resist apply keep work piece into dryer for four minute. Expose the photo tool and masked work piece together in such way that the work piece should be below the photo tool. Rinse the work piece in developer solution for some time till visibility of figure on work piece. Wash it in running water. Then the chemical etching operation is carried out in etching machine i.e. either a hot plate or the water bath adjust the time and temperature as per experiment planning. The thickness of specimen was 2 mm and cut at 10mmX10mm dimension. $FeCl_3$ chemical etchant was prepared. 100 ml amount of Fecl3 was prepared for each run. In this paper single sided photochemical etching was conducted. The measurements of Undercut were carried out by Rapid - I. Fig. 3, shows schematic representation of Photochemical machining experimental setup.


a) Material before machining


b) Square Phototool



c) Photoresist Solution


d) UV Exposure Unit



e)Chemical etching


d) Finished Part

Figure 2 Experimental setup of Photo chemical machining

4. RESULTS AND DISCUSSION

4.1. Development of Regression Model Equation

Centre composite design was used to develop correlation between the undercut during the PCM process of SS316L material to concentration, temperature and time. Experimental error was determined by using 20 experiments at the centre point. Associate to the sequential model sum of squares, the models were selected based on the F-value. The independent input variables of the model were significant so that the models were not aliased and the full quadratic model was taken as proposed by the software Minitab-17. Based on full quadratic model, experiments were planned to obtain 20 trials plus a star configuration (0, ±1) and their duplicates at the centre point. Table IV shows the design of experiment, together with the experimental results. The minimum undercut was found to be 0.0815mm. Regression analysis was performed to fit the response function of undercut. The mathematical model expressed by Eq. 1, where the variables fill their coded values, represents the Undercut (Ud) as a function of time (A), temperature (B) and concentration(C).

Ud= 0.09139+0.06062*(A3)+ 0.0583*(B3)+ 0.0041*(C3) -0.00985*(A3*A3) + 0.02955*(B3*B3) -0.00545 *(C3*C3)+0.024875*(A3*B3) - 0.000875*(A3*C3)+0.001625*(B3*C3) (1)

TABLE III Analysis of Variance Table for Undercut (mm)

Term	Coef	SE Coef	T	P
Constant	0.091390	0.001608	56.848	0.000
TIME	0.060620	0.001479	40.993	0.000
T	0.058300	0.001479	39.424	0.000
C	0.004100	0.001479	2.773	0.020
TIME*TIME	-0.009850	0.002820	-3.493	0.006

Term	Coef	SE Coef	T	P
T*T	0.029550	0.002820	10.479	0.000
C*C	-0.005450	0.002820	-1.933	0.082
TIME*T	0.024875	0.001653	15.045	0.000
TIME*C	-0.000875	0.001653	-0.529	0.608
T*C	0.001625	0.001653	0.983	0.349
S=0.004676	R-Sq=99.7%		R-Adj=99.5%	

Based on the ANOVA with full quadratic results obtained in Table V, time and temperature were found to have significant effects on Undercut of SS316L. With the help of this statistical model we have tried to find out the significant and non-significant terms in the variables (Table V), so non-significant terms are omitted in the developed mathematical model. Actual values were calculated through response surface data for a particular run & the predicted values were evaluated from the model by using the regression equation and were generated by using the approximating functions. The fair correlation coefficients might have resulted by the insignificant terms in Table V, and most likely due to different variables chosen in wide ranges with a limited number of tests as well as the nonlinear effect of the investigated parameters on process response.

4.2. Statistical Analysis

Although additional trials are required to fully confirm the results, the actual and the predicted undercut during the PCM process of SS316L material are shown in Fig. 3, Actual values are the experimentally performed response data for a certain experimentrun as per the design of experiment and the predicted values are measured from the RSM design and regression equation. This plot explains the effectiveness of the developed mathematical model. The difference between the actual and predicted values with centre composite design by coded values is shown in Table IV. It is clear that model provided values are quite close to the experimental values.

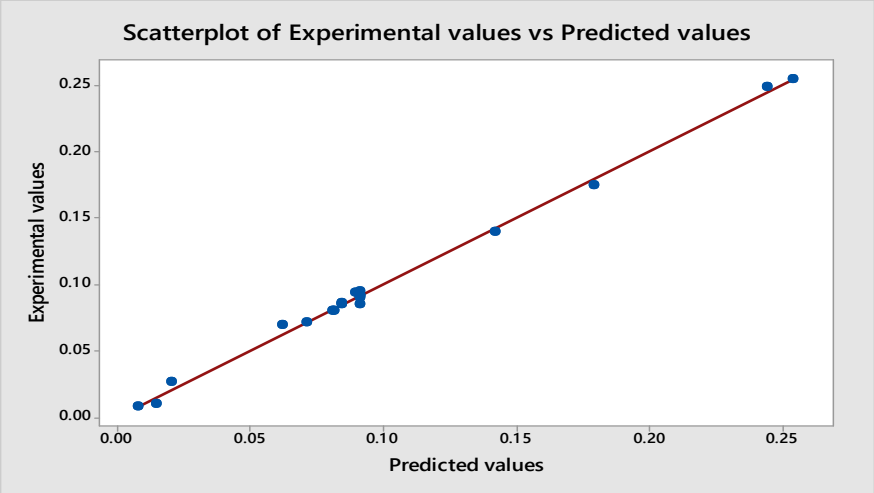


Figure 3 The Actual and Predicted Plot of Undercut of SS316L.

TABLE IV RSM Model Adequacy Check for Undercut

Run Order	Time (min)	Temperature (^{0}C)	Concentration (gm/lit)	Experimental values of Ud	Predicted values of Ud	Error %
1	-1	-1	-1	0.008	0.008245	3.0625
2	0	0	0	0.085	0.091390	7.5176
3	0	0	0	0.092	0.091390	0.6630
4	1	0	0	0.1392	0.142160	2.1264
5	-1	0	0	0.026	0.020920	19.538
6	-1	-1	1	0.01	0.014945	9.45
7	-1	1	1	0.086	0.085045	1.1104
8	1	-1	1	0.085	0.084685	0.3705
9	1	1	1	0.254	0.254285	0.1122
10	0	1	0	0.175	0.179240	2.4228
11	0	0	-1	0.08	0.081840	2.3
12	0	0	0	0.095	0.091390	3.8
13	0	-1	0	0.069	0.062640	9.2173
14	-1	1	-1	0.071	0.071845	1.1901
15	1	-1	-1	0.08	0.081485	1.8562
16	0	0	1	0.094	0.090040	4.2127
17	0	0	0	0.092	0.091390	0.6630
18	0	0	0	0.0905	0.091390	0.9834
19	0	0	0	0.0896	0.091390	1.9977
20	1	1	-1	0.249	0.244585	1.7730

Three-dimensional plots were drawn to investigate the effects of the time, concentration and temperature factors on the undercut during the PCM process of SS316L material. Fig.4 shows 3D graph of undercut as a function of time and temperature. From graph, it is observed that Undercut is minimum a low level of temperature at low time level; it increases with increase in time. Fig.5 shows 3D graph of undercut as a function of time and concentration. From graph, it is observed that Undercut is minimum at mean level of concentration at low time level; it increases with increase in time. Fig. 6 shows 3D graph of undercut as a function of temperature and concentration. From graph, it is observed that Undercut is minimum at mean level of concentration at low and mean temperature level; it increases with increase in temperature. The mean level of all three parameter is important where there is change in undercut is observed.

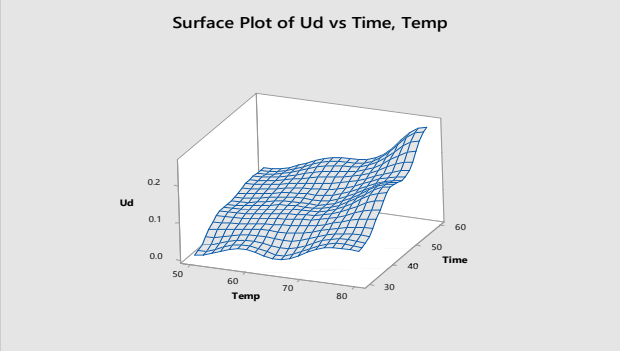


Figure 4 Surface plot of Ud vs. Time, Temp

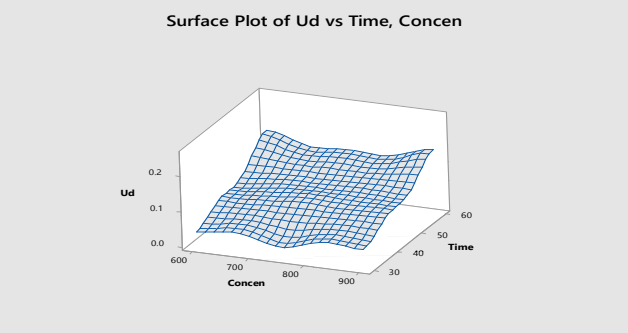


Figure 5 Surface plot of Ud vs. Time, concentration

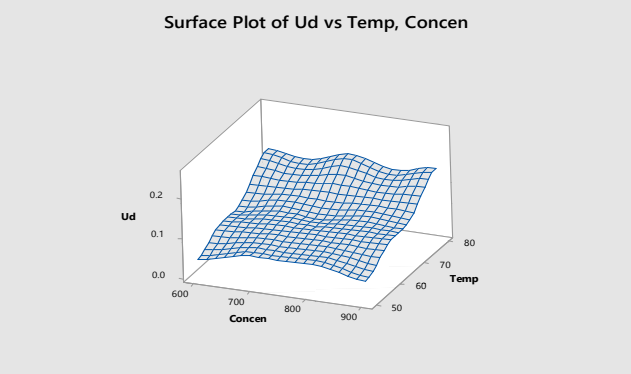


Figure 6 Surface plot of Ud vs. Temp, concentration

4.3. Optimization by Response Surface Modelling

The main purpose of this study was to find out the optimum process parameters to minimize undercut during the PCM process of SS316L material from the developed mathematical model equations. For optimization MITNITAB is used. The optimum Undercut conditions determined for PCM process on SS316L materials shown in Table V.

TABLE V. Optimization Result of PCM of SS316L

Desirability	Temp. (°C)	Time (min)	Conc. (gm/lit)	Undercut(mm)
0.96	63.99	46.96	769.69	0.0815

5. CONCLUSIONS

The response surface methodology based on three variables, centre composite design was used to determine the effect of time, concentrations of etchant and temperature on the Undercut during the PCM process of SS316L material. Full quadratic models were developed to show a relationship between variables and the responses. Through analysis of the response surfaces derived from the models, role of time and temperature was found to have the most significant effect on Undercut. Process optimization was carried out and the experimental values acquired for the Undercut during the PCM process of SS316L material are found to agree satisfactorily with the values predicted by the models using regression equation. Since experimentally obtained and model predicted values are residual which shows the effectiveness of model, based on the designed experiment. The optimal predicted Undercut 0.0815mm of SS316L was obtained at optimum level of concentration, time and temperature of etching and these were found to be 769.69gm/lit, 46.96 min and 63.99^0C respectively.

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